Techno-Economic Analysis of Receiver Replacement Scenarios in a Parabolic Trough Field

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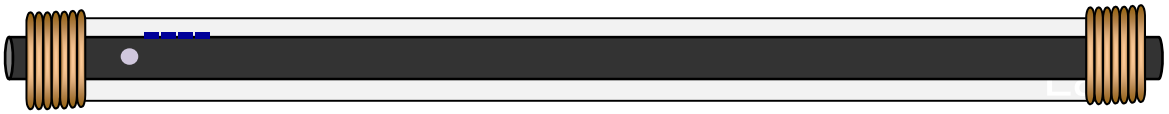
Overview

1. **MOTIVATION** of Study
2. **REFERENCE** Parabolic Trough Plant
3. **SCENARIOS** for Receiver Performance Loss
4. **METHODOLOGY**
5. **RESULTS**
6. **CONCLUSIONS**

1. MOTIVATION of Study



- **Field heat losses** are between **7%** (Jordan, Ma'an) and **10%** (Guadix, Spain) of the collected solar energy (Eurotrough-type, 70mm absorber, HTF: Oil)
- Receiver design lifetime is **20-40 years**
- However, lifetime may be reduced by
  - Different maturity of products
  - Limited experience in operation, H_2 accumulation in HTF
  - Increasing temperatures and new fluids
  - Wind events with glass breakage
- In case of failure, receiver heat loss may be increased by a **factor 5 to 10**
- **Objective of study**: Energetic and economic impact of different receiver performance loss scenarios

2. REFERENCE Parabolic Trough Plant

Technology

- Modern **150-MW_{el} parabolic trough plant** in **Ma'an**, Jordan (DNI 2820 kWh/m^2a)
- **7.5h**-molten salt storage
- 360 loops of **high-quality collectors** (η_{opt}= 0.78) (Eurotrough-geometry)
- **51'840 receivers** (totaling 207 km), either standard or with Xe-capsule (+1.3% solar field cost est.)
- **Turbine 150 MW**, efficiency 38.5%
- **Dry cooling**, no fossil firing

Economy

- Investment costs 4 M€/MW_{el}
- Annual O&M + Ins.: 2.4%*I
- Discount rate 6%, 25% equity, 75% debt (5% interest rate), 25 yrs operation

→ **LEC 11.3 €cent/kWh_{el}**

3. SCENARIOS for Receiver Performance Loss

Event

- "**Wind A/B**" Wind event destroying glass envelopes
- "**H_2**" Hydrogen accumulation
- "**AR**" Anti-reflection coating degradation

Affected Field

- **50%** (H_2) or **100%** (AR) of field
- Limits of field (**5.6%**, Wind)

Variation of *point in time* when damage occurs

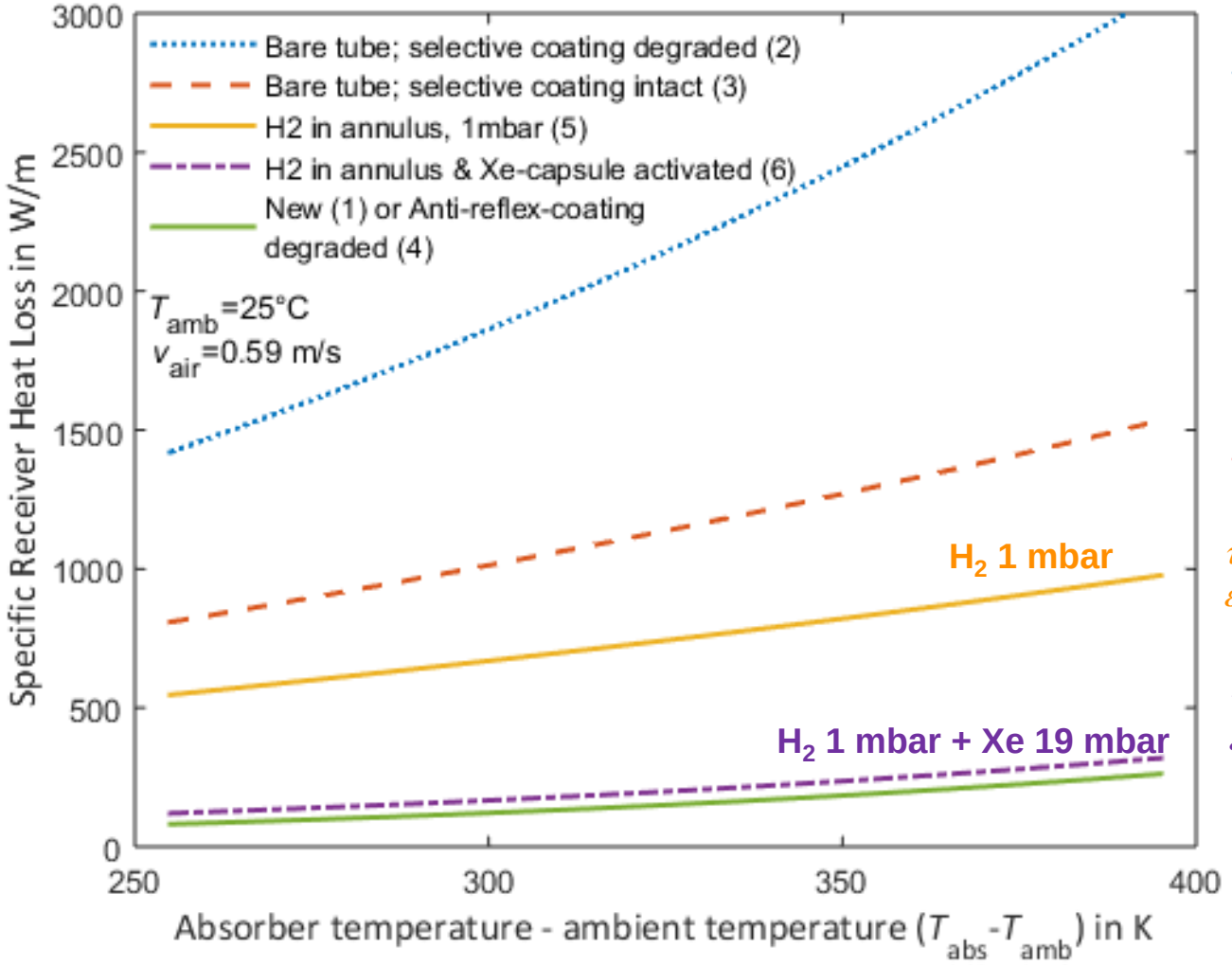
- **sudden** event year ***t*=5**, **10**, or **15**
- **gradual** damage (AR) **1..5**, **1..10**, **1..15**

Different counter measures (full performance in year t+2)

- "**Leave**" damaged receivers (do nothing)
- "**Replace**" damaged receivers
- Activate "**Xenon**" capsule (H_2 accumulation)
- "**Fix**" receivers (H_2 accumulation)

3. SCENARIOS for Receiver Performance Loss

Heat Loss of Regarded Receivers



τ=100%; α_{sol} = 55%, ε=65%, free convection

τ=100%; α_{sol} = 96%, ε=8-9%, free convection

τ=97%; α_{sol} = 96%, ε=8-9%, **h_{ann}=12.4 W/m²K**

τ=97%; α_{sol} = 96%, ε=8-9%, **h_{ann}=0.8 W/m²K**

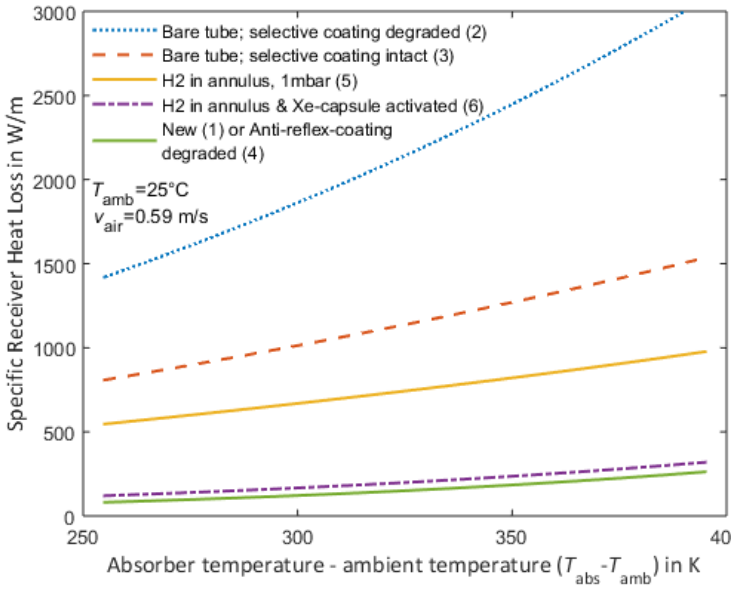
τ=97/92%; α_{sol} = 96%, ε=8-9%, h_{ann}=0.0 W/m²K

3. SCENARIOS for Receiver Performance Loss

Heat Loss of Regarded Receivers

Wind strongly influences bare and H_2 receivers. Increase of air speed near receivers from 0.6 to 3.0 m/s leads to higher heat losses:

- **With intact envelope** + 6 W/m
- **H_2 accumulation** +100 W/m
- **Bare tubes with broken envelope** +1000-2000 W/m



Relation between air speed interacting with receivers and 10m wind speed derived from measurements of [Dudley]

- 10m wind speed of 3.8 m/s (Ma'an)
  → 0.6 m/s air speed near receivers

V. Dudley, G. Kolb, M. Sloan, D. Kearney, "Test Results, SEGS LS-2 Solar Collector," Sandia National Laboratories, Report SAND94-1884, Dec. 1994

4. METHODOLOGY

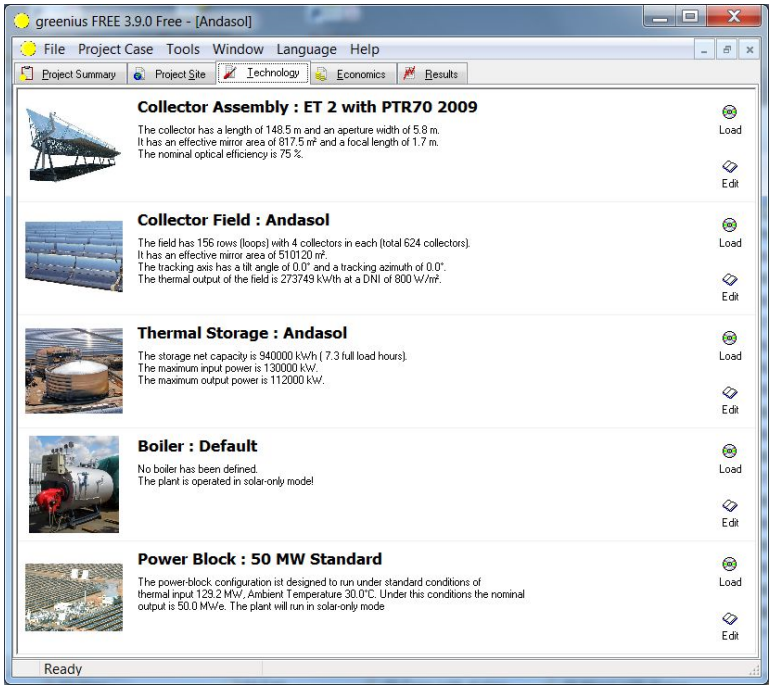
greenius + Matlab

*Software **greenius*** (http://freegreenius.dlr.de)

- Performance calculations of CSP & other renewable systems based on hourly plant performance simulations

Special version created to represent

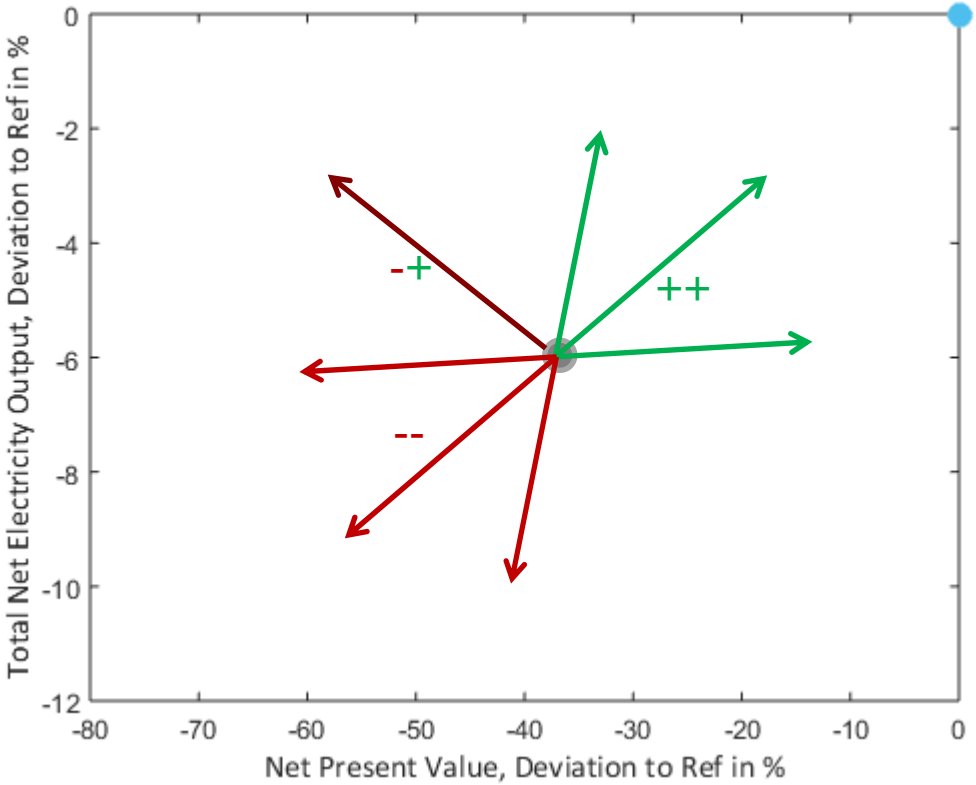
- **Spatially inhomogeneous** collector loops
- **Temporal variation** of optical and thermal receiver quality
- **Additional investments** for repair at specific points in time ***t*+1** possible
- Calculation of **each** year
- greenius start from **DOS / Matlab prompt** and preparation of input files and post-processing with Matlab



greenius

THE GREEN ENERGY SYSTEM ANALYSIS TOOL

5. RESULTS



Net Present Value *(x-axis)*

- is the discounted value of the cumulated project cash flows at time zero
- is a **measure for economic success** of a project

Total Net Electricity Output *(y-axis)*

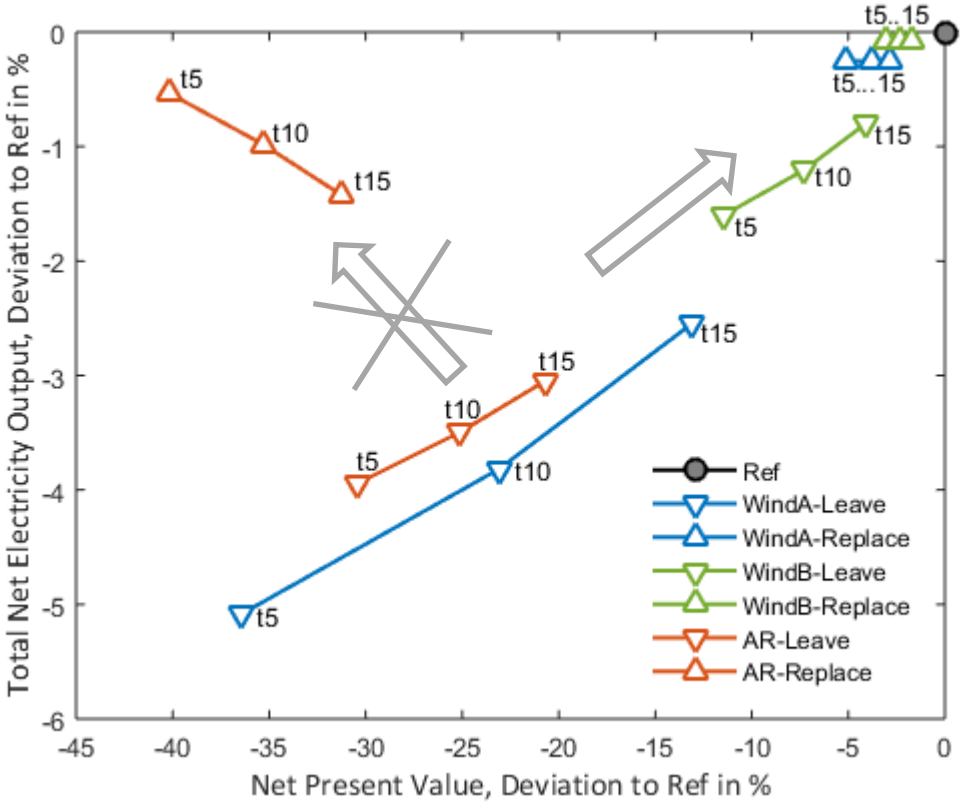
- is the total net electrical output of the plant **over 25 years**

Plotted is the **deviation to the reference scenarios** (‘Ref’ or ‘Ref-Xe’)

For maximum electricity production and maximum economic success
→ **move right and up**

5. RESULTS

Wind (‘A’/’B’) and Anti-reflection Coating (‘AR’) Scenarios

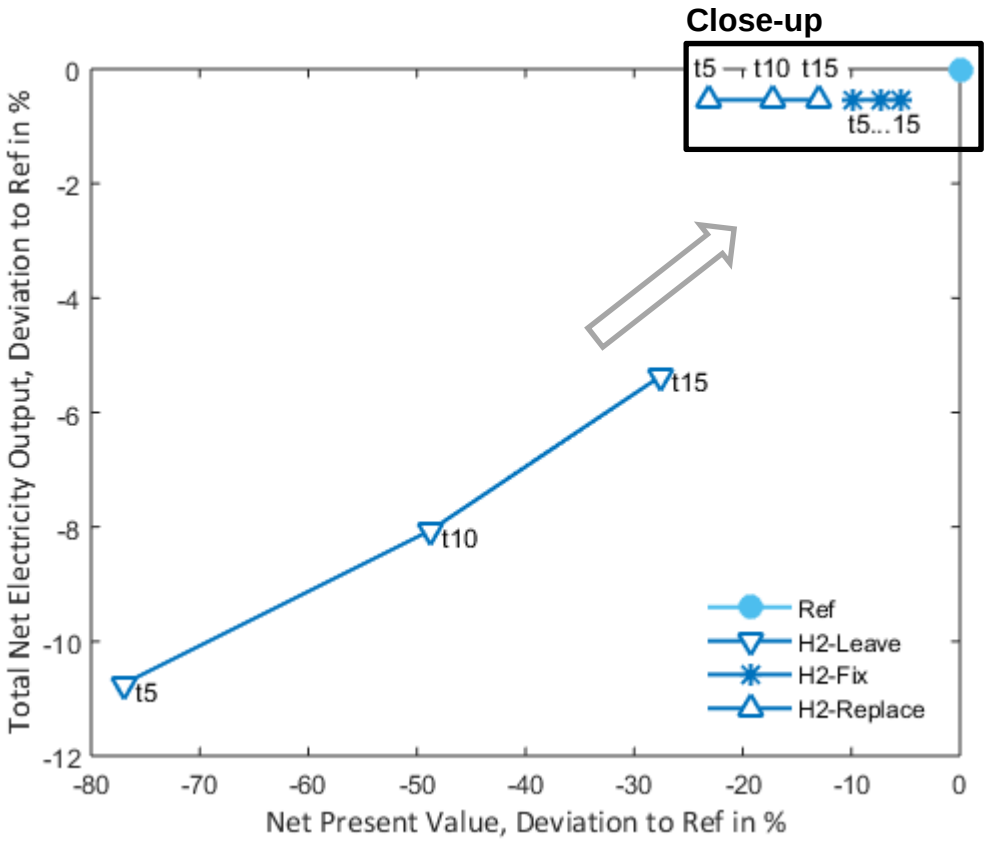


*Replace: ~1 k€/rec. (rec. 600€ + labour 400€ + Loop outage)

- **WindA** (degr. coating) event may reduce **net present value up to 36%** and total generated **electricity up to 5%** over plant lifetime
- **Replacement*** is both economically and energetically **viable**
- **WindB** (stable coating) is similar but less pronounced
- **AR** scenario may reduce **net present value up to 30%** and **electr. up to 4%**
- **Replacement*** is energetically viable, but **economically NOT viable**

5. RESULTS

Hydrogen Scenarios ('H2')



- **H_2** may reduce **net present value up to 77%** and total generated **electricity up to 11%** over plant lifetime
- **Replacement*** is both economically and energetically **viable**
- **Fixing**:** If there is a **repair** solution for standard receivers, this would be the **most viable solution**

*Replace: ~1 k€/rec. (rec. 600€ + labour 400€ + Loop outage)

**Repair/Fix : 200€/rec. assumed

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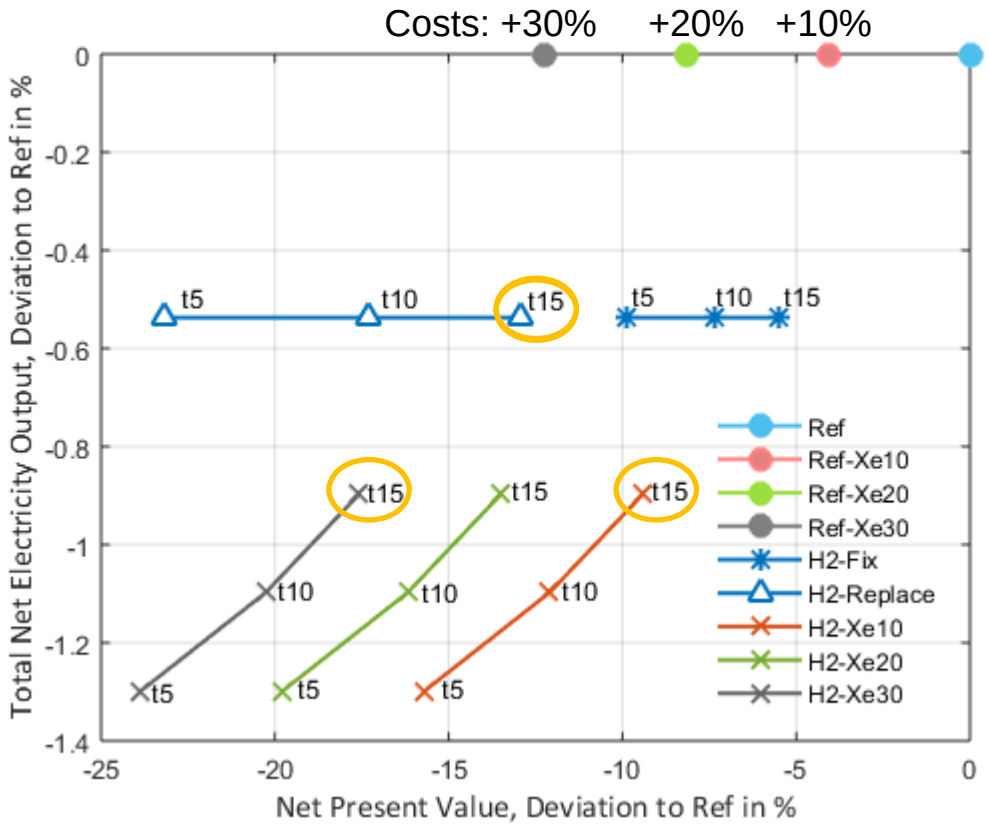
5. RESULTS

Hydrogen Scenarios (‘H2’)



*Replace: ~1 k€/rec. (rec. 600€ + labour 400€ + Loop outage)

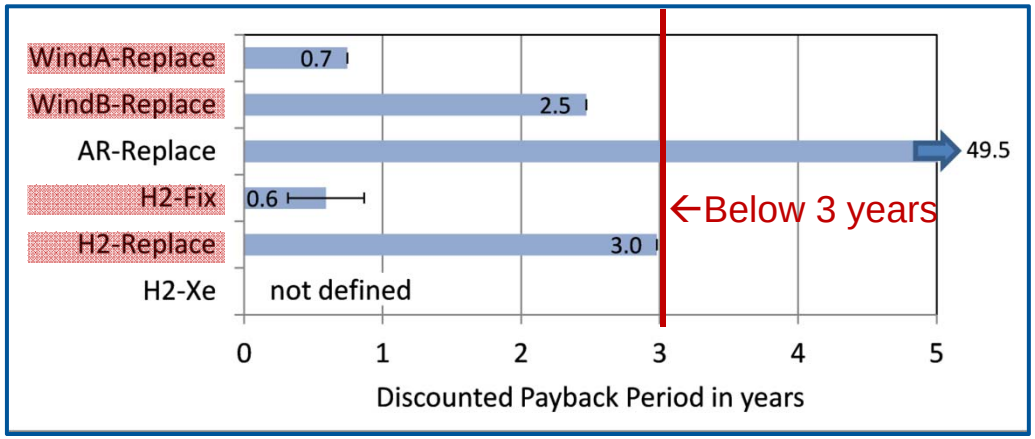
**Repair/Fix : 200€/rec. assumed

Xe receivers:

- Reference ‘Ref-Xe’ scenarios have lower net present value, because of higher initial investment
- Xe10 / Xe20 / X30: surplus of +10% / 20% / 30% costs compared to standard receivers
- Xe10: In case of H_2 accumulation, ‘H2-Xe10’ more viable than standard receiver replacement ‘H2-Replace’
- Xe30: Not viable comp. to ‘H2-Replace’
- Xe20: Depends on point of time of damage

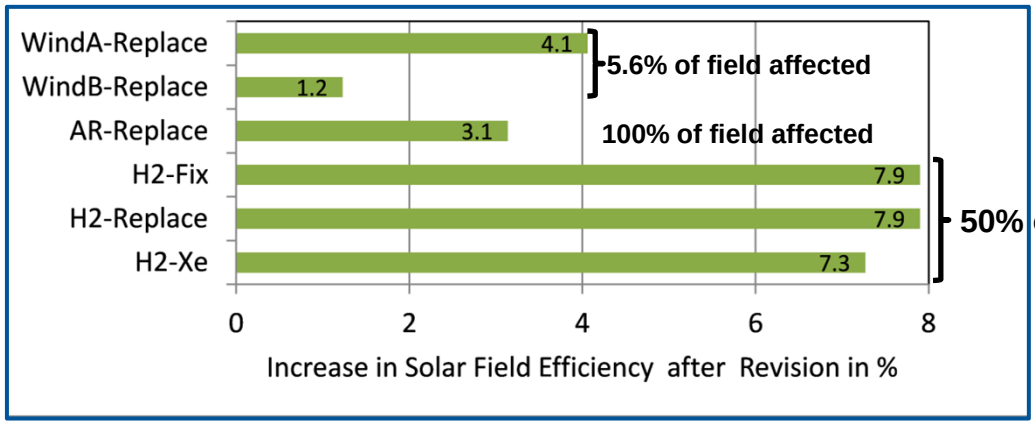
5. RESULTS

Discounted Payback Period



Discounted Payback Period
=Time after which the additional investment has been amortized by the additional revenues

Payback period is **below 3 years** for all measures except for Replacement in AR case



Efficiency Increase of Counter Measure

6. Conclusions (I)

- A **method** to investigate the **energetic and economic impact** of different **receiver performance loss scenarios** was presented.
- The software tool **greenius** was extended and coupled to Matlab

6. Conclusions (II)

The following results are of exemplary character and only valid under the assumed boundary conditions. Plant Owner should repeat the calculations for their own conditions with the proposed method.

- ***Reference***: **150-MW_{el}-parabolic trough** plant with **7.5-h**-molten-salt-storage
- ***Scenarios***: **Wind** breakage, **H_2** accumulation, anti-reflection coating degradation (**AR**) in event year **5**, **10**, or **15** and **counter-measures**

- ***Wind**:* **Receiver replacement** of receivers with broken glass envelope has a **payback period of 0.7 to 2.5 years** and hence replacement is strongly recommended
- ***H2***: Hydrogen accumulation has the highest impact, reducing output up to 11% and net present value by 77%. Receiver **replacement** (**payback 3 years**) or **repair** (**payback 0.6 years**) is economically and energetically required.
- ***H2-Xe**:* The option of investing in receivers with **Xe-capsule** is a viable option, only if the **surplus cost is lower than 10 to 20%** and H_2 accumulation occurs.
- ***AR***: **Replacement is NOT viable**.

THANK YOU

for your attention.

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